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(54) **SYSTEM AND METHOD FOR SOLAR-POWERED CONTROL OF EXHAUST AFTER-TREATMENT SYSTEMS**

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CPC B60K 16/00; B60K 1/04; B60K 2016/003; F01N 3/2026

USPC 60/284, 286, 300, 303

See application file for complete search history.

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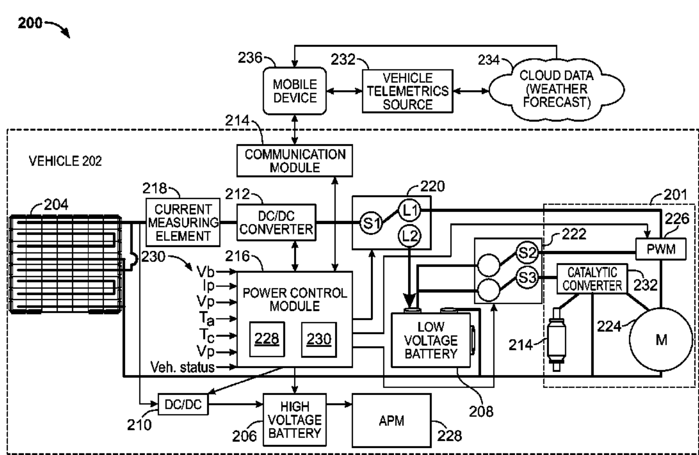
(57) **ABSTRACT**

A system and method for providing energy to auto systems such as systems after-treating exhaust. Energy may be received from a solar energy source electrically connected to an after-treatment system. At least some of the energy from the solar energy source may be provided to the after-treatment system to purify exhaust from an engine. A control module may provide at least some of the energy from the solar energy source to a heater, for example, to initiate heating the after-treatment system prior to starting the engine. The heater may heat the after-treatment to temperatures within a predetermined temperature range associated with optimal efficiency for the after-treatment system.

20 Claims, 10 Drawing Sheets



(51) **Int. Cl.**

F01N 3/027	(2006.01)
F01N 3/20	(2006.01)
B60K 13/04	(2006.01)

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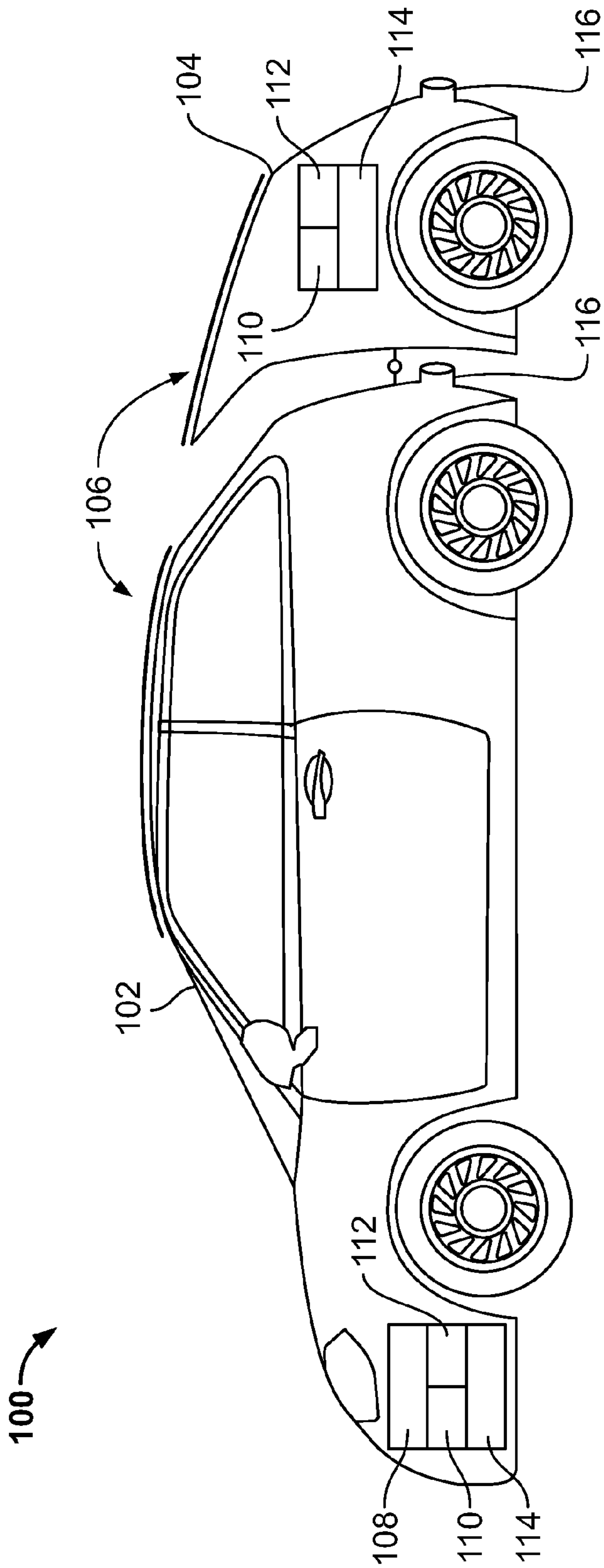


FIG. 1

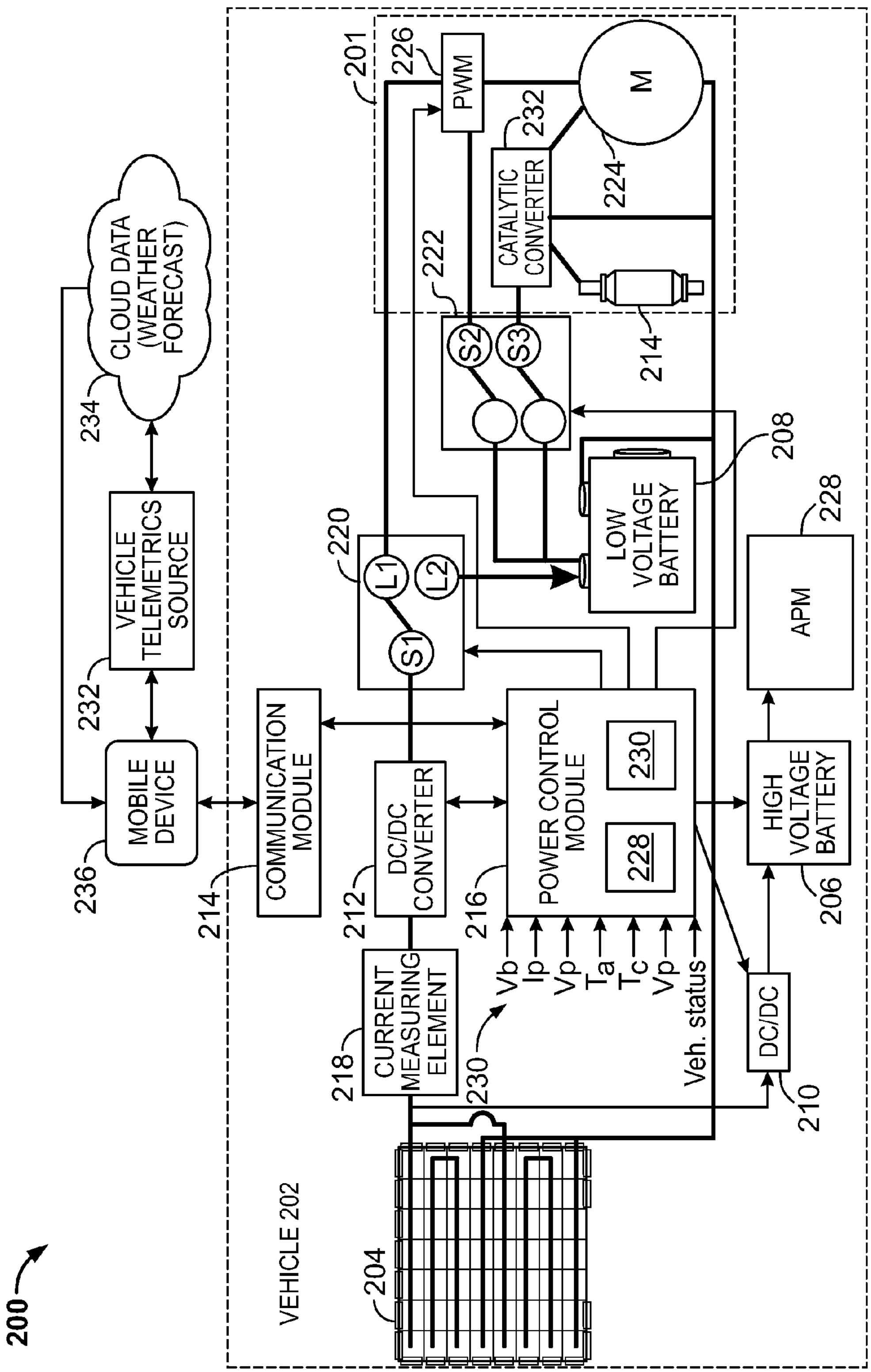

200
VEHICLE 202
204
CURRENT MEASURING ELEMENT
218
230
Vb
Ip
Vp
Ta
Tc
Vp
Veh. status
DC/DC
210
DC/DC CONVERTER
212
POWER CONTROL MODULE
216
228
230
HIGH VOLTAGE BATTERY
206
APM
228
COMMUNICATION MODULE
214
MOBILE DEVICE
236
VEHICLE TELEMETRICS SOURCE
232
CLOUD DATA (WEATHER FORECAST)
234
220
S1
L1
L2
LOW VOLTAGE BATTERY
208
222
S2
S3
214
CATALYTIC CONVERTER
232
PWM
226
201
M
224

FIG. 2

300 302 304 306

VEHICLE STATUS	SOLAR POWER	TEMP	BATTERY VOLTAGE	S1L1	S1L2	S2	S3	MODES	PWM
1-DRIVE; 0-PARK	1-SUN; 0-MOON			BATT ONLY	BATT + FAN	LOAD	CAT		X = BLOWER MOTOR Y = BATTERY Z = AFTER-TREATMENT COMP
1	0	N/A	N/A	0	0	0	0	SLEEP 1	X=0%; Y=0%; Z=0%
0	0	N/A	N/A	0	0	0	0	SLEEP 2	X=0%; Y=0%; Z=0%
0	1	>TREF	>MAX	0	1	0	0	BLOWER ON 1	X=100%; Y=0%; Z=0%
0	1	>TREF	MAX>VBATT>MID	1	1	0	0	BLOWER ON 2	X=80%; Y=20%; Z=0%
0	1	>TREF	MID>VBATT>MIN	1	1	0	0	BLOWER ON 3	X=40%; Y=60%; Z=0%
0	1	<TREF	MAX>VBATT>MID	1	0	0	0	TRICKLE CHARGE	X=0%; Y=60%; Z=0%
0	1	<TREF	MID>VBATT>MIN	1	0	0	0	BULK CHARGE	X=0%; Y=100%; Z=0%
0	1	<TREF	>MAX	0	1	0	1	AFTER-TREATMENT	X=0%; Y=0%; Z=100% (PARKED)
1	1	<TREF	>MAX	0	1	0	1	AFTER-TREATMENT	X=0%; Y=0%; Z=100% (DRIVE)

FIG. 3

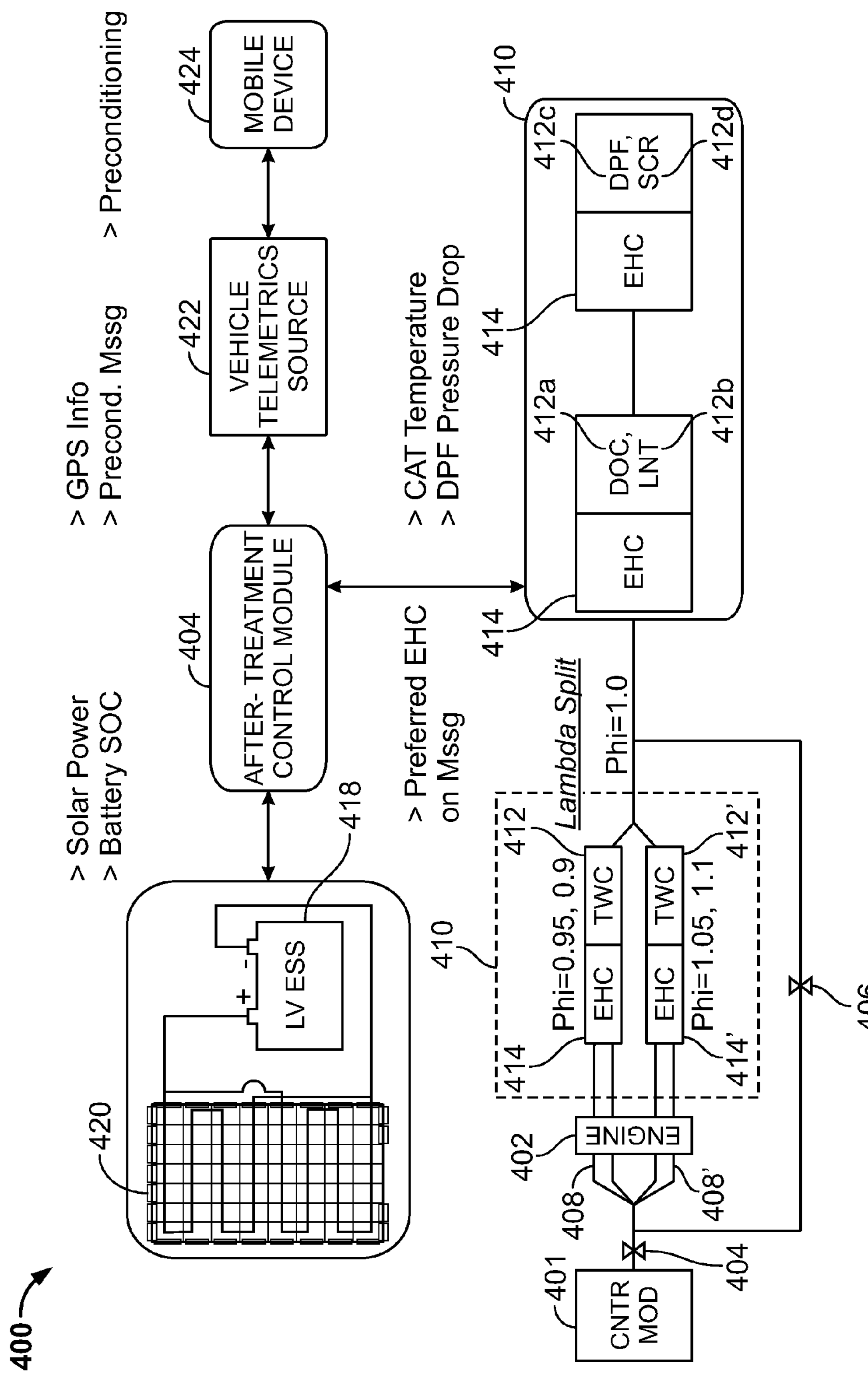
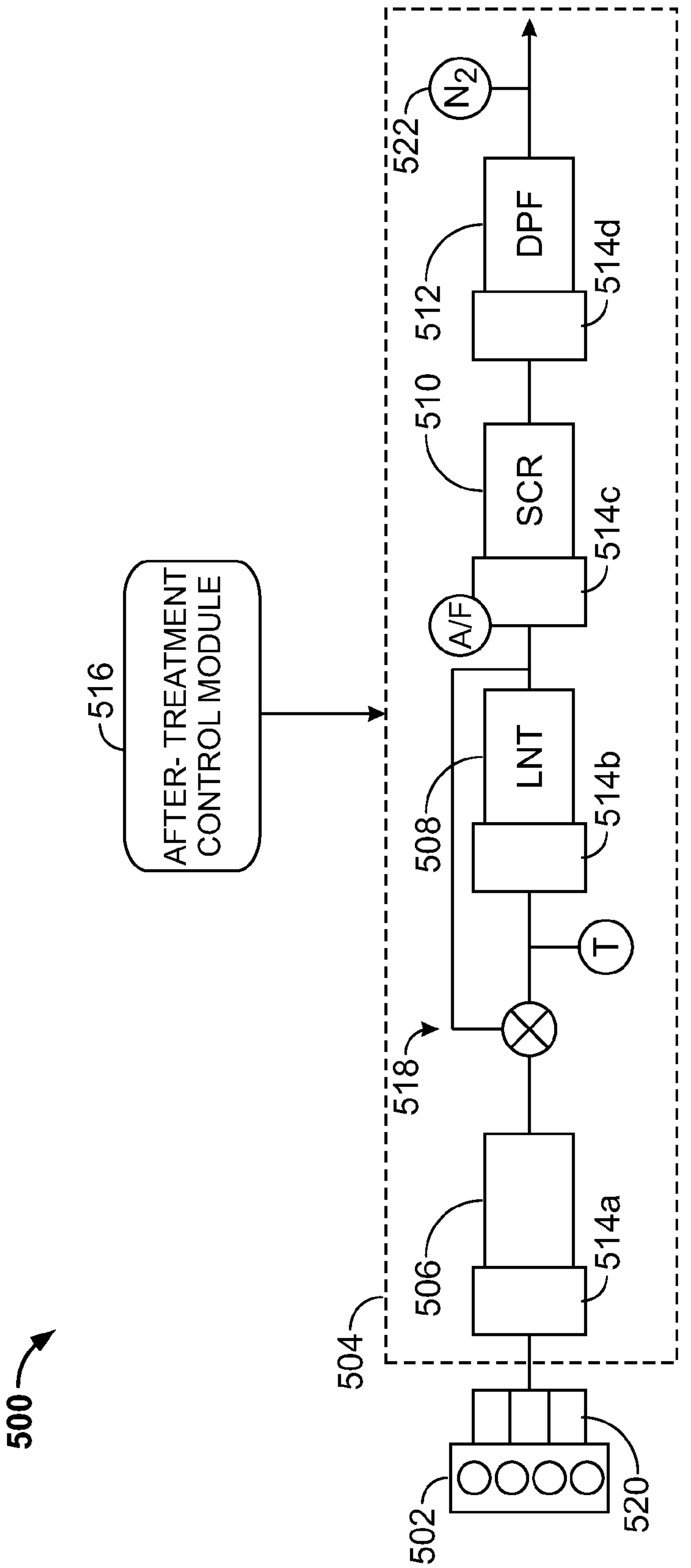

400
> Solar Power
> Battery SOC
> GPS Info
> Precond. Mssg
> Preconditioning
420
418
LV ESS
+
-
404
AFTER- TREATMENT CONTROL MODULE
422
VEHICLE TELEMETRICS SOURCE
424
MOBILE DEVICE
> Preferred EHC on Mssg
> CAT Temperature
> DPF Pressure Drop
410
414
EHC
412a
DOC, LNT
412b
414
EHC
412c
DPF, SCR
412d
Lambda Split
Phi=1.0
410
412
Phi=0.95, 0.9
EHC
TWC
414
EHC
TWC
Phi=1.05, 1.1
412'
414'
402
ENGINE
408
408'
401
CNTR MOD
404
406

FIG. 4



500
502
520
504
506
514a
518
T
508
LNT
514b
AFTER- TREATMENT
CONTROL MODULE
516
A/F
SCR
514c
510
512
514d
DPF
522
N_2

FIG. 5

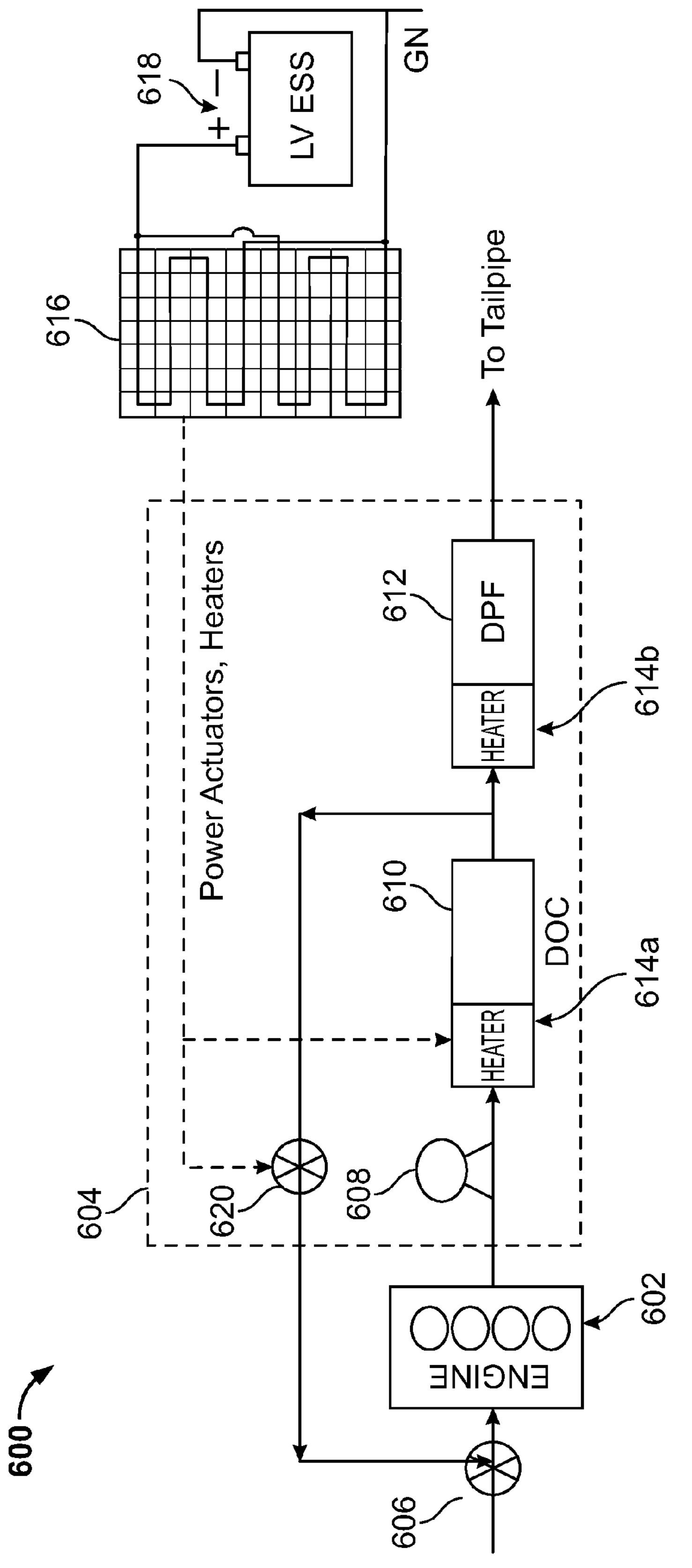

600
602
ENGINE
604
606
608
620
HEATER
614a
610
DOC
Power Actuators, Heaters
HEATER
614b
612
DPF
To Tailpipe
616
618
+
−
LV ESS
GN

FIG. 6

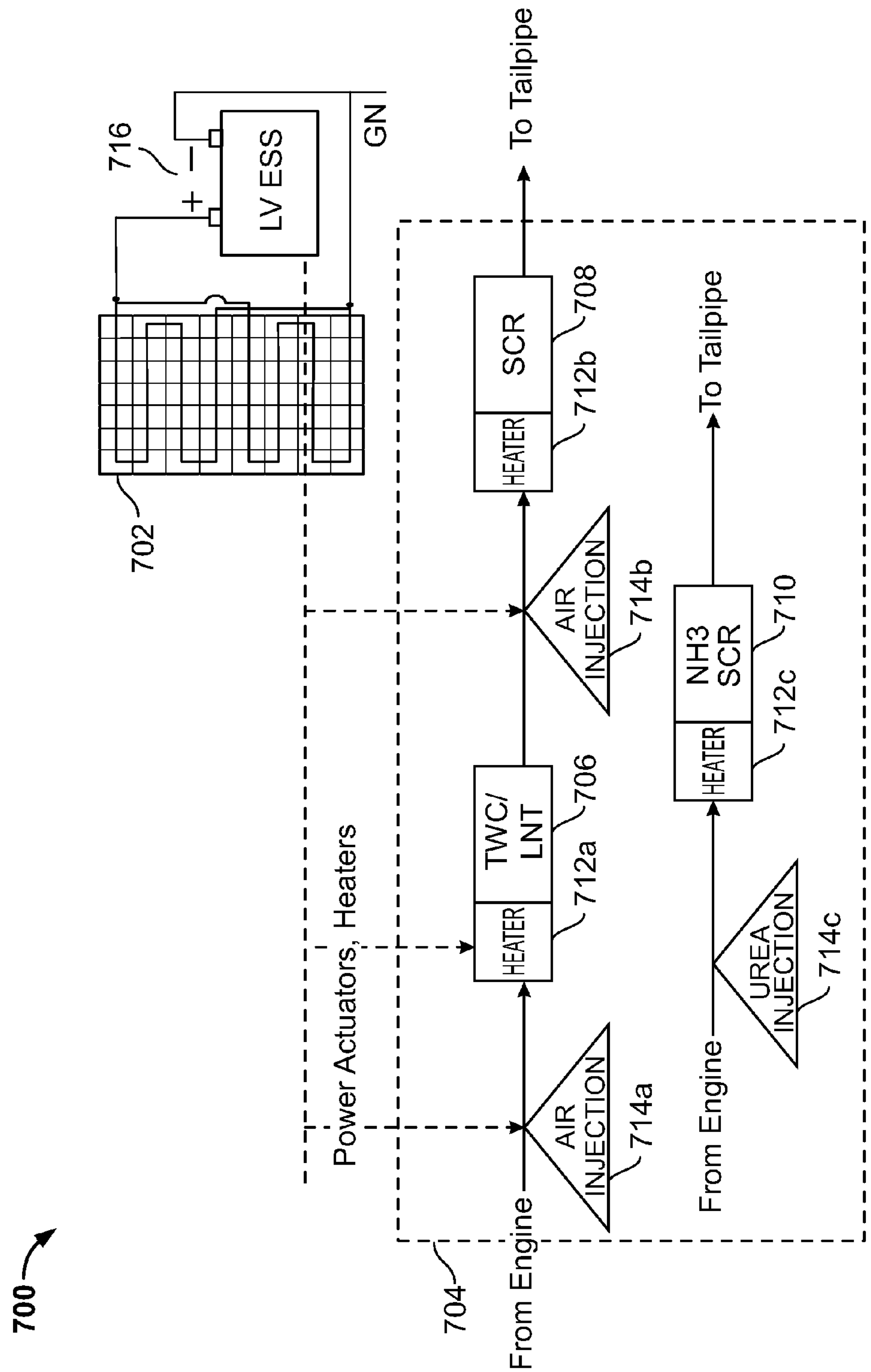

700
702
716
LV ESS
+
–
GN
Power Actuators, Heaters
704
From Engine
AIR INJECTION
714a
HEATER
TWC/ LNT
712a
706
AIR INJECTION
714b
HEATER
SCR
712b
708
To Tailpipe
From Engine
UREA INJECTION
714c
HEATER
NH3 SCR
712c
710
To Tailpipe

FIG. 7

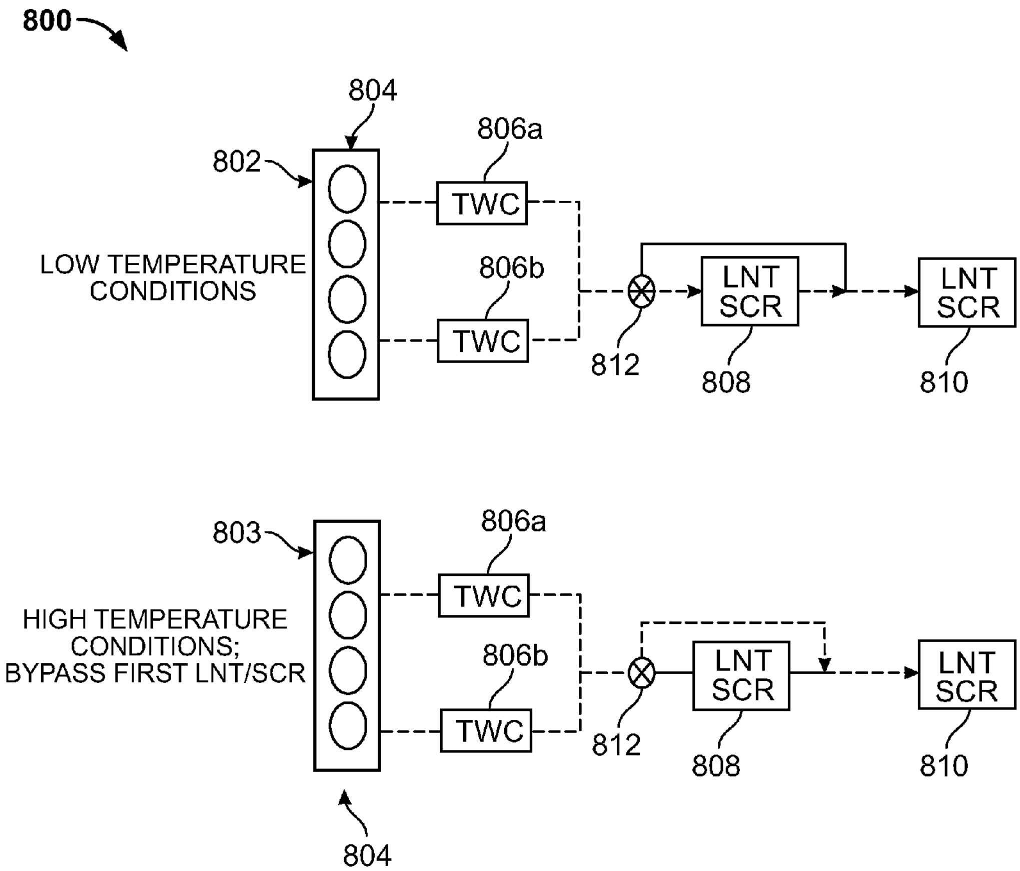

800
804
806a
802
TWC
LOW TEMPERATURE
CONDITIONS
806b
LNT
SCR
LNT
SCR
TWC
812
808
810
803
806a
TWC
HIGH TEMPERATURE
CONDITIONS;
BYPASS FIRST LNT/SCR
806b
LNT
SCR
LNT
SCR
TWC
812
808
810
804

FIG. 8

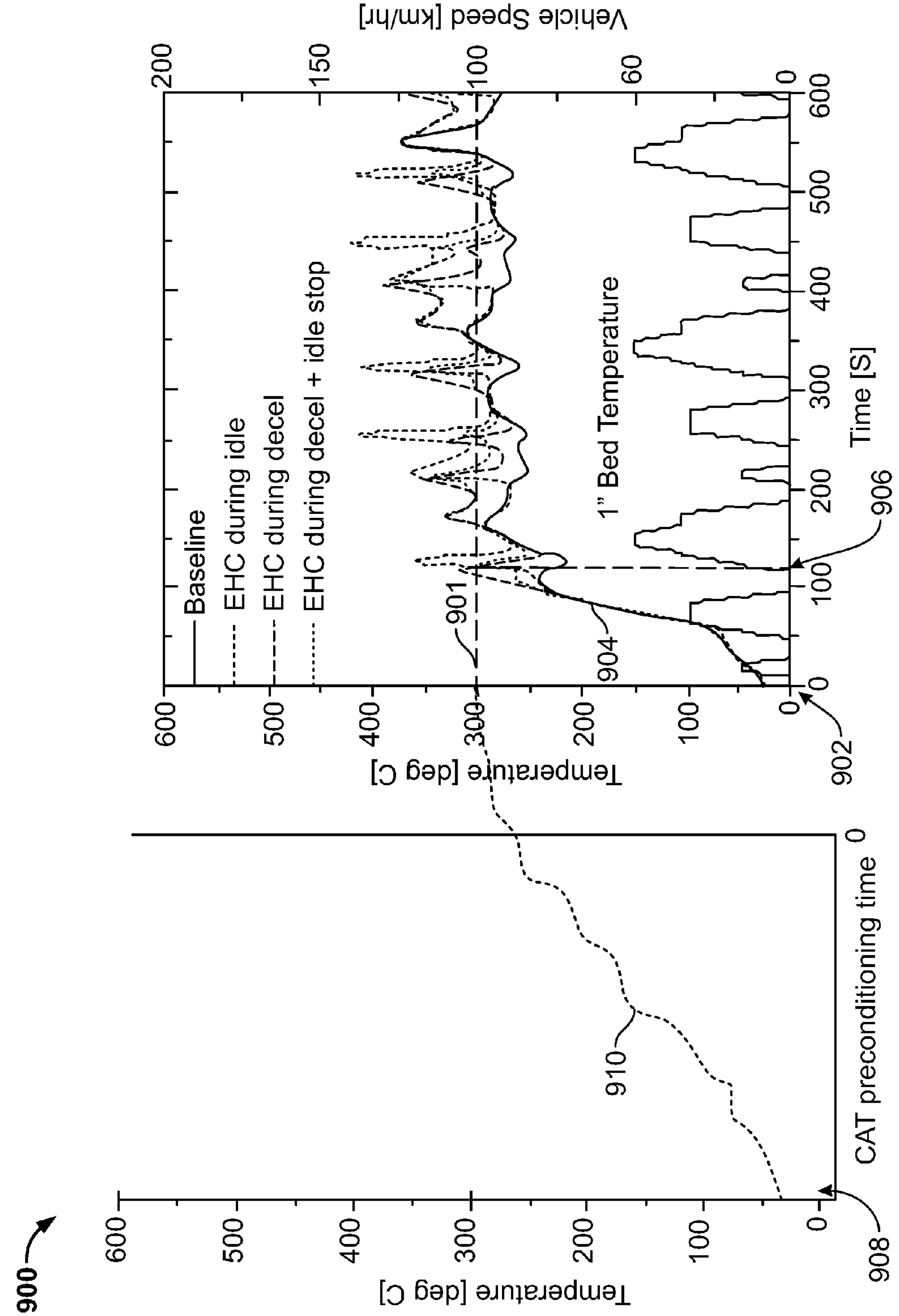

900
Temperature [deg C]
600
500
400
300
200
100
0
908
910
CAT preconditioning time
0
Vehicle Speed [km/hr]
200
150
100
60
0
Baseline
EHC during idle
EHC during decel
EHC during decel + idle stop
901
904
1" Bed Temperature
906
902
Time [S]
100
200
300
400
500
600

FIG. 9

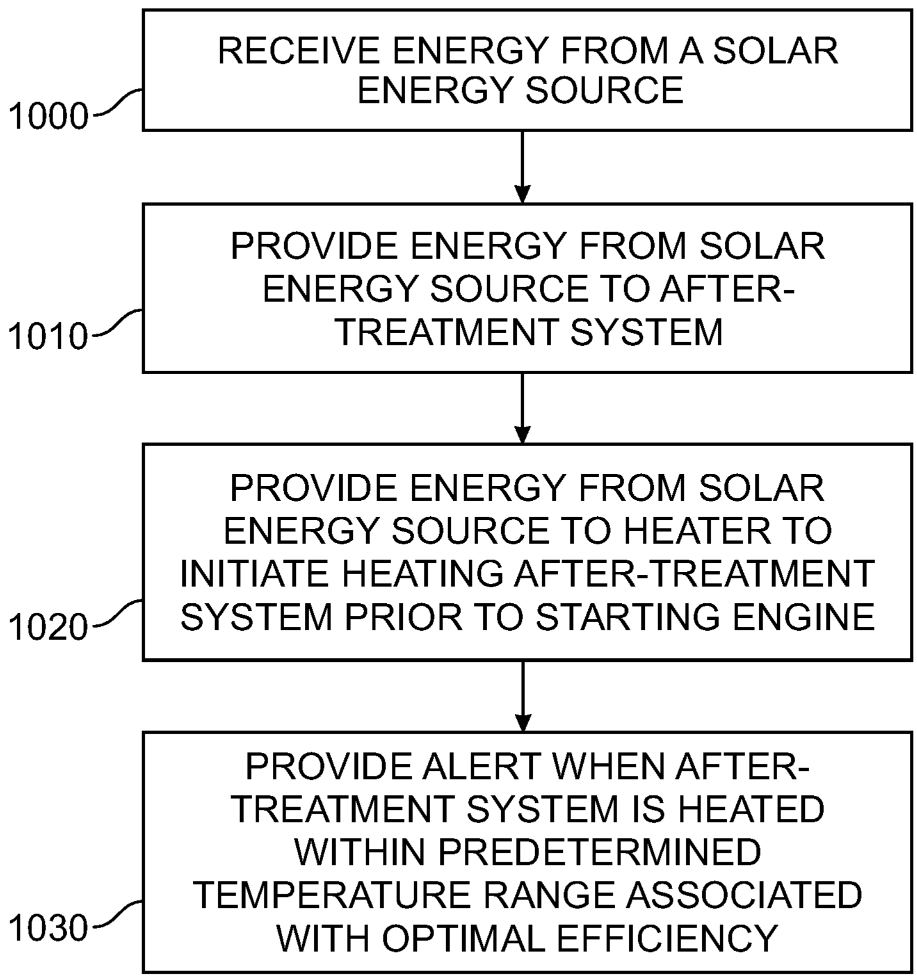

RECEIVE ENERGY FROM A SOLAR ENERGY SOURCE
1000
PROVIDE ENERGY FROM SOLAR ENERGY SOURCE TO AFTER-TREATMENT SYSTEM
1010
PROVIDE ENERGY FROM SOLAR ENERGY SOURCE TO HEATER TO INITIATE HEATING AFTER-TREATMENT SYSTEM PRIOR TO STARTING ENGINE
1020
PROVIDE ALERT WHEN AFTER-TREATMENT SYSTEM IS HEATED WITHIN PREDETERMINED TEMPERATURE RANGE ASSOCIATED WITH OPTIMAL EFFICIENCY
1030

FIG. 10

SYSTEM AND METHOD FOR SOLAR-POWERED CONTROL OF EXHAUST AFTER-TREATMENT SYSTEMS

TECHNICAL FIELD

The present invention is related to exhaust after-treatment systems and methods to clean or purify exhaust from, for example, internal combustion or diesel engines. In particular, the present invention is related to powering after-treatment systems using solar energy.

BACKGROUND

Exhaust gas after-treatment systems and methods aim to reduce exhaust emissions, such as carbon monoxide (CO), unburned hydrocarbons (UHC), NOx and particulate emissions. After-treatment systems may include three-way catalysts (TWC), oxidation catalysts, particulate filters, lean NOx traps, and catalytic converters, such as a selective catalytic reduction catalyst (SCR catalyst) or a urea-selective catalytic reduction catalyst, located downstream of an internal combustion engine.

Nitrogen oxides (NOx) emissions may include nitric oxide (NO) and nitrogen dioxide (NO2). These gases may be harmful to the environment and are restricted according to emission standards, such as, Tier 2, EURO V, Euro VI, low emissions vehicle (LEV) I, LEV II and LEV III. Existing NOx reduction technologies, such as, lean NOx traps and catalytic converters, may reduce NOx emissions to cleaner substances, such as, nitrogen (N2) and water (H2O).

Exhaust gas may have high temperatures, for example, in a range of from approximately 200° C. to approximately 400° C. for a warmed up diesel engine. After-treatment systems may have optimal performance (e.g., a maximum reduction in undesirable emissions) at high temperatures in ranges of from, for example, 250° C. to 350° C. for catalytic converters, 600° C. to about 700° C. for diesel particulate filters (sufficiently hot to burn soot), and 250° C. to about 500° C. for lean NOx traps (sufficiently hot to desulfate or remove sulfur from the trap). These temperature ranges for optimal after-treatment performance may vary depending upon the type of engine and after-treatment process.

These elevated temperatures are typically achieved through the use of an oxidation catalyst or in the case of a diesel engine a diesel oxidation catalyst (DOC), which generates an exothermal reaction with raw hydrocarbons that are included in or injected into the exhaust stream, such as by in-cylinder injection or external injection directly into the exhaust stream.

If the temperatures of the after-treatment systems fall outside these ranges, the after-treatment performance may be compromised and undesirable emissions may increase. For example, each time a car is started, idle, or stops and then starts, the after-treatments system may cool and may be unable to optimally purify the exhaust, thereby contributing to elevated pollutant levels in the air.

SUMMARY OF THE INVENTION

In some embodiments, energy may be received from a solar energy source electrically connected to an after-treatment system. At least some of the energy from the solar energy source may be provided to the after-treatment system to purify exhaust from an engine. A control module may provide at least some of the energy from the solar energy source to a heater, for example, to initiate heating the after-treatment system prior to starting the engine. The heater may heat the after-treatment to temperatures within a predetermined temperature range associated with optimal efficiency for the after-treatment system.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. **1** is a schematic diagram of a vehicle and an after-treatment system according to an embodiment of the present invention;

FIG. **2** is a schematic diagram of a solar-powered after-treatment system according to an embodiment of the present invention;

FIG. **3** is a chart defining different modes for allocating energy to different components in a vehicle according to an embodiment of the present invention;

FIGS. **4-8** are schematic diagrams of systems according to embodiments of the invention;

FIG. **9** is a graph of temperatures of an after-treatment system for an engine with respect to time according to an embodiment of the present invention; and

FIG. **10** is a flowchart of a method according to an embodiment of the present invention.

Reference numerals may be repeated among the drawings to indicate corresponding or analogous elements. Moreover, some of the blocks depicted in the drawings may be combined into a single function.

DETAILED DESCRIPTION OF THE DRAWINGS

In the following description, various aspects of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well known features may be omitted or simplified in order not to obscure the present invention.

Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "processing," "computing," "calculating," "determining," or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulates and/or transforms data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices.

A vehicle after-treatment system may have optimal efficiency at a specific range of elevated temperatures. However, heating the after-treatment system to these temperatures may take time to achieve. The time it takes to heat the after-treatment system may depend on many factors including the target temperatures for the specific after-treatment system, available energy reserves in the vehicle, ambient temperature or weather conditions, the operational mode of the vehicle, for example, whether the vehicle is parked, stopped, driving, accelerating, etc. In one example, a vehicle may take up to several minutes to properly heat an after-treatment system.

Conventional systems may power or provide energy to after-treatment systems using energy from a vehicle battery. The battery may only begin to provide energy to the after-treatment system once the vehicle's engine is started (and may not provide energy when the engine is off or may provide a reduced amount of energy when idling). Accordingly, there may be a time delay after a vehicle has just been started and/or each time the vehicle idles when the after-treatment system has not yet reached optimal temperatures. The after-treatment system may operate with sub-optimal efficiency during these time delays, for example, emitting undesirable amounts of contaminated exhaust.

According to embodiments of the invention, an after-treatment system may use solar power to power (e.g. heat) after-treatment systems. Solar power energy or electricity may be captured via for example one or more (e.g., a network of) solar power cells mounted on the vehicle that may provide direct power or power via an intermediate battery to heat after-treatment systems (e.g., by directing electricity to such systems). The solar power energy may be managed independently (or dependently) of other vehicle energy systems (e.g., the main vehicle battery) and may provide power or energy, for example, even when the vehicle engine is off. Since the solar power energy source does not depend on the main battery, the after-treatment system may begin to be heated prior to starting the engine, for example, to be fully (or partially) pre-heated to optimal temperatures by the time the engine is started. In one embodiment, the after-treatment system may be pre-heated or started a time prior to starting the engine which is less than, equal to, or greater than the time typically used to achieve the system's optimal functional temperature. In some embodiments, solar power sources may have a longer time delay to pre-heat the after-treatment system (e.g., twenty minutes) than conventional vehicle energy sources (e.g., two to four minutes) and may be started earlier to account for the extra length of the time delay.

Fluctuations in available energy from the solar power energy source may further affect the time used to heat the after-treatment system by solar power. For example, on a sunny day, solar power energy sources may provide more energy and may take less time to power the after-treatment system than during a cloudy day or during nighttime. In some embodiments, to account for such solar fluctuations, the solar energy sources may have an energy reserve or battery (e.g., separate from the main vehicle battery). Therefore, the vehicle solar energy source may harness solar energy from the Sun during sunlight hours and may store the energy to power the after-treatment system at any time, regardless or currently available solar power (for example, during daytime as well as during nighttime).

Accordingly, a solar-powered after-treatment system in a vehicle may be pre-heated, for example, to optimal temperatures for optimal efficiency, prior to starting the vehicle engine. Accordingly, the conventional time delay during which the vehicle emits noxious exhaust in the minutes after starting the vehicle may be eliminated or at least reduced.

FIG. **1** is a schematic diagram of a vehicle **100** and an after-treatment system according to an embodiment of the present invention. Vehicle **100** (e.g. a locomotive device such as an automobile, truck, plane, boat, forklift, etc., or non-locomotive device such as a mining equipment or other engine-equipped machine) may include a main body **102** and optionally, an auxiliary power unit (APU) **104**. Main body **102** may be a standard vehicle and may provide at least driving capabilities. Auxiliary power unit **104** may include an extension that may be integral to or detachable from main body **102**.

Vehicle **100** may include photovoltaic (solar) power sources **106**. Photovoltaic sources **106** may include one or a plurality of interconnected individual solar cells, solar laminate film, solar cured glass and/or surface coatings. Photovoltaic sources **106** may be mounted on either or both of main body **102** and auxiliary power unit **104**. Photovoltaic sources **106** generating electricity may be mounted on any surface of vehicle **100** that may potentially be incident to the sun, for example, including the roof, trunk lid, front hood, bumpers, window guards, the windows themselves via photovoltaic glass laminate or cured glass, or any combination thereof. Photovoltaic sources **106** may be positioned at a fixed position or orientation or, using a device for tracking sun position, may be moved or movable, or rotated to a position or orientation to collect the maximal amount of solar power. Various arrangements may provide a total area of photovoltaic sources **106** of, for example, from approximately one square meter (e.g., mounted only on the roof) to about two to three square meters (e.g., mounted on the roof, trunk and hood). Photovoltaic sources **106** may generate, for example, 200 to 400 watts of power for vehicle **100**.

Vehicle **100** may include an engine **108** providing mechanical power to move the vehicle and components such as a fork lift. Engine **108** may be any hydrocarbon or hybrid hydrocarbon/electric fueled power source, such as an internal combustion engine, a diesel engine, a gasoline engine, a hydrocarbon portion of hybrid powertrain or any combination thereof.

Vehicle **100** may include energy storage systems (ESS) or batteries **110** and/or **112** for storing energy in main body **102** and/or auxiliary power unit **104**. Battery **110** may include one or more low-voltage (e.g., 12 volt) batteries and battery **112** may include one or more high-voltage (e.g., 300 volts or greater) batteries. In some embodiments, low-voltage battery **110** may be used for relatively low-power tasks, for example, operating windshield wiper motors, power seats, or power door locks, powering a starter for an internal combustion engine, and/or powering an after-treatment system **114**. In some embodiments, high-voltage battery **112** may be used for either or both low or high-power tasks, where high-power tasks may include, for example, powering the traction motors (if included) of vehicle **100** and propelling vehicle **100**.

Photovoltaic sources **106** may be electrically connected to charge or store energy generated thereby in either or both of low-voltage and/or high-voltage batteries **110**, **112**. Low-voltage battery **110** may be charged over a range of temperatures of from, for example, −20 degrees Celsius (° C.) to 50° C. The voltage used to charge low-voltage battery **110** may exceed the storage voltage of, for example, 12 volts. In one example, the charging voltage of a lead-acid battery over this temperature range may be from approximately 13.5 to 16.5 volts. To charge high voltage battery **112**, a plurality of interconnected photovoltaic sources **106** may be connected to a DC-DC convertor to increase the voltage, for example, to about 300 volts. To charge both low and high-voltage batteries **110**, **112**, a step-down DC-DC convertor may be used to reduce voltages to additionally charge low-voltage battery **110**. In yet another embodiment, photovoltaic sources **106** may be connected to form at least two separate arrays with one generating power to high-voltage battery **112** at high-voltage battery-charging voltages and a second generating power to low-voltage battery **110** at low-voltage battery-charging voltages. Any suitable configuration of photovoltaic or solar material or cells may be used, for example, in combination with a DC-DC convertor to increase charging voltage or a step-down DC-DC convertor to decrease charging voltage, to achieve any target charging voltage. In some embodiments, photovoltaic sources **106** may charge low and high-voltage batteries **110**, **112** equally, or one before the other, for example, only charging low-voltage battery **110** after high-voltage battery **112** is fully charged or vice versa.

Vehicle **100** may include an after-treatment (A/T) system **114**. After-treatment system **114** may reduce undesirable exhaust emissions for example including NOx and particulate emissions. After-treatment system **114** may include a TWC, particulate filters, lean NOx traps, hydrocarbon traps, oxidation catalysts, and catalytic converters, such as a selective catalytic reduction catalyst (SCR catalyst) or a urea-selective catalytic reduction catalyst. After-treatment system **114** may be located downstream of engine **108** and upstream of an exhaust system **116**, such that emissions from engine **108** pass through after-treatment system **114** to purity exhaust before being expelled into the environment via exhaust system **116**. Exhaust system **116** may be disposed on either or both of main body **102** and auxiliary power unit **104**.

FIG. **2** is a schematic diagram of a solar-powered after-treatment system **200** according to an embodiment of the present invention.

System **200** may include a vehicle **202** (e.g., vehicle **100** of FIG. **1**) having an after-treatment system **201** (e.g., after-treatment system **114** of FIG. **1**). Vehicle **202** may include photovoltaic (solar) electric power sources **204** (e.g., photovoltaic sources **106** of FIG. **1**), such as, an array of solar energy cells and/or laminate. Vehicle **202** may include one or more high-voltage batteries **206** (e.g., high-voltage battery **112** of FIG. **1**), one or more low-voltage batteries **208** (e.g., low-voltage battery **110** of FIG. **1**) and/or one or more auxiliary power modules (APM) **228** (e.g., auxiliary power unit **104** of FIG. **1**).

A power control module **216** may control the allocation of energy (e.g. in the form of electricity) from photovoltaic sources **204** to each of vehicle **202** components (e.g., catalytic converter **214** and/or blower motor **224**). Power control module **216** may use a current measuring element **216** to measure the electric power output of photovoltaic sources **204** to determine the power adjustment necessary to charge or power each of vehicle **202** components. Power control module **216** may use DC-DC converters **210**, **212** to adjust (e.g., increase or decrease) the voltage output of photovoltaic sources **204**.

Power control module **216** may transfer energy (e.g. in the form of electricity) from photovoltaic sources **204** to high-voltage battery **206** (e.g., and/or APM **228**) at the correct high-voltage battery charging voltage, for example, via DC-DC converter **210** and to low-voltage battery **208** at the low-voltage battery charging voltage, for example, via DC-DC converter **212**. Energy may be transferred to batteries **206**, **208** and/or APM **228** independently or, alternatively, first to high-voltage battery **206** and/or APM **228** and, upon saturating the storage capacity or reaching an above threshold amount of stored energy, subsequently transferred to low-voltage battery **208** (or vice versa). Current measuring element **218** may be used to measure current or electricity output from the photovoltaic sources **204** to determine the available electricity from solar power for distribution. Power control module **216** may also transfer electric energy (e.g. in the form of electricity) from photovoltaic sources **204** (e.g., either directly or via an intermediate storage component, such as, low-voltage battery **208**) to after-treatment system **201** components including a catalytic converter **214** and/or a blower motor **224**. Power control module **216** may adjust voltage output to each of the after-treatment components according to the component's specific system standards (e.g., and according to different modes in FIG. **3**), for example, via DC-DC converter **212** and may be split between after-treatment components, for example, via pulse-width modulation (PWM) device **226**.

Power control module **216** may include a processor **228** and memory **230** to divert energy (e.g. in the form of electricity) to vehicle **202** components via one or more switches **220**, **222**. In one example, switch **220** may distribute energy to low-voltage battery **208** (e.g., in actuated position (L**2**)) or to blower motor **224** (e.g., in actuated position (L**1**)) and switch **222** may distribute energy from low-voltage battery **208** to blower motor **224** (e.g., in actuated position (S**2**)) or to catalytic converter **214** (e.g., in actuated position (S**3**)) or a heater **232** thereof. Blower motor **224** may be used to circulate heat to the catalytic converter **214**. Other switches or arrangements of switches may be used to transfer energy between any components in vehicle **202**.

After-treatment system **201** may include a catalytic converter, a diesel oxidation catalyst (DOC), a lean NOx trap, and/or a particulate filter. To achieve optimal after-treatment reactions, heat may be generated and circulated to catalytic converter **214** via blower motor **224** until catalytic converter **214** is heated to temperatures within an optimal temperature range (e.g., defined according to the after-treatment process and specifications of the catalytic converter).

Power control module **216** may input information **230** to determine (e.g., at processor **228**) the appropriate amount of energy to transfer to after-treatment system **201** to heat catalytic converter **214** within the optimal temperature range. Information **230** may include data on conditions that affect the optimal amount of energy or power to allocate to catalytic converter **214**, heater **232** and/or blower motor **224** to achieve the optimal temperature. Information **230** may include, for example, voltage of one or more energy sources (Vb) (e.g., low-voltage battery **208**), output current of photovoltaic source **204** (Ip), voltage of photovoltaic source **204** (Vp), ambient temperature (Ta), cabin temperature (Tc), minimum power to operate power control module **216** (5 Volts), and/or vehicle mode (e.g., parked mode, driving mode) (Veh. status). Information **230** may include additional or different conditions.

Vehicle **202** may include internal devices, such as, an internal computer, processor **228** and memory **230**, temperature, voltage and/or current sensors, and/or switches **220**, **222** activated by predefined environmental conditions, for example, to store, retrieve or generate information **230**, such as, Vb, Ip, Vp, Tc, and min power. Vehicle **202** may also include a communication module **220** to communicate with external devices to retrieve or generate information **230**, such as, Ta and Veh. status. External devices may include a vehicle telemetrics source **232** such as, a global positioning system (GPS), a weather service source **234** providing information related to weather, terrain, altitude, or other environmental information, and a mobile computing device **236**, such as, a mobile computer, a smart phone, a tablet computer, a personal digital assistant (PDA), etc., which may have a wireless network connection to retrieve temperature, weather, geographic or environmental condition information from external devices or servers. Alternatively, any or all of the information **230** may be obtained by devices internal to vehicle **202** or external to vehicle **202**.

Power control module **216** may use information **230** to select one or more modes defining where the energy from photovoltaic sources **204** is transferred. In one example, power control module **216** may transfer energy according to modes, for example, as defined in FIG. **3**. Power control module **216** may provide energy by providing a current at a voltage (to result in a certain power level), which may be predetermined according to the voltage of the energy source (e.g., high-voltage battery **206**, APM **228** or low-voltage battery **208**).

FIG. **3** is a chart defining relationships between a plurality of different energy modes **304** for allocating energy to different components in a vehicle (e.g., vehicle **100** of FIG. **1**) and a plurality of conditions **300** according to an embodiment of the present invention. When a set of conditions **300** are detected, a control module may select a corresponding mode **304** for operation. Conditions **300** may include, for example, vehicle driving status or modes (e.g., if the vehicle is in park (**0**) or drive (**1**)), solar power (e.g., if there is light from the sun (**1**) or moon (**0**)), if a measured temperature is greater than, less than, or equal to a reference temperature (Tref), and available battery voltage (e.g., if the voltage of one or more energy sources (Vb) such as low-voltage battery **208** of FIG. **2** is within a maximum, mid, or minimum voltage range). The measured temperature may be for example a cabin temperature (Tc), current temperature of the after-treatment system, current exhaust gas temperature when the vehicle is operating, etc. The reference temperature (Tref) may be the optimal temperature (or temperature range) for an after-treatment system. The reference temperature (Tref) may also be equal to the difference between the ambient temperature (Ta) and the cabin temperature (Tc) (Tref=Ta−Tc)).

Each one of the plurality of energy modes **304** may correspond to a set of switch positions **302** and energy allocations **306**. Energy allocations **306** may define the amount or percentage of energy (e.g., electricity) generated at a solar energy source to be allocated to different components of the vehicle. The energy may be distributed directly from the solar energy source (e.g., photovoltaic sources **106** of FIG. **1**) or via an intermediate energy storage system (e.g., low-voltage battery **110** of FIG. **1**). The components in the example in FIG. **3** are blower motor (X) (e.g., blower motor **224** of FIG. **2**), battery (Y) (e.g., low-voltage battery **208** of FIG. **2**) and one or more after-treatment components (e.g., catalytic converter **214** of FIG. **2**), although other components may be used. Energy modes **304** in the example in FIG. **3** include "Sleep **1**" (e.g., 0% energy allocated to components during drive mode), "Sleep **2**" (e.g., 0% energy allocated to components during park mode), "Blower ON **1**" (e.g., 100% energy allocated to the blower), "Blower ON **2**" (e.g., 80% energy allocated to the blower and 20% energy allocated to the battery), "Blower ON **3**" (e.g., 40% energy allocated to the blower and 60% energy allocated to the battery), "Trickle Charge" (e.g., 60% energy allocated to the battery), "Bulk Charge" (e.g., 100% energy allocated to the battery), "After-Treatment" (e.g., 100% energy allocated to the after-treatment component(s) or associated parts, such as, a heating device or coil to heat the catalytic converter), although other modes may be used. A power control module (e.g., power control module **216** of FIG. **2**) may store these relationships between conditions **300** and the energy allocations **306** for energy modes **304**, for example, in a memory unit (e.g., memory **230** of FIG. **2**).

The power control module may use a pulse-width modulation (PWM) device (e.g., PWM device **226** of FIG. **1**) to divide electric energy from the solar energy source in different proportions among each of the different components based on conditions **300**, for example, according to energy allocations **306**.

FIG. **4** is a schematic diagram of a system **400** according to an embodiment of the present invention.

System **400** may include an engine **402** and a throttle **404**. Engine **402** may be an internal combustion engine, a diesel engine, a gasoline engine, an electric engine, a hybrid engine, etc. Throttle **404** may control the supply of power to engine **402**. For internal combustion engines such as diesel or gasoline engines, throttle **404** may control the fuel or gasoline supplied to engine **402**, while for electric and/or hybrid engines, throttle **404** may control the electricity supplied and/or the mix of electricity and gasoline used. A control module **401** may control the flow of fuel to engine **402** by controlling the opening and closing of the one or more exhaust gas recirculation ('EGR') valves **406**.

The fuel may be sent to two (or more) sets of combustion chambers **408** and **408'** in which the fuel may be combusted (oxidized) to power engine **402**. In some embodiments, control module **401** may cause fuel to be provided to combustion chambers **408** and **408'** using for example lambda split fuel injection, in which fuel is injected into the first set of combustion chambers **408** to operate at a "rich" or relatively high air/fuel ratio (e.g., phi=0.95-0.9), and fuel is injected into the second set of combustion chambers **408'** to operate at a "lean" or relatively low air/fuel ratio (e.g., phi=1.05-1.1).

Control module **401** may control the ignition of each combustion chamber **408** and **408'**, for example, at a time delay, to propel a piston on a crankshaft or a turbine disk in a gas turbine engine, and run engine **402**. Each set of combustion chambers **408** and **408'** may have respective exhaust valves **406** that are in fluid (e.g., liquid or gas) communication with different exhaust manifolds to output exhaust, for example, via an exhaust pipe. Combustion byproducts may exit combustion chambers **408** and **408'** as exhaust and pass into the exhaust gas feedstream to an exhaust after-treatment system **410**.

After-treatment system **410** may reduce the toxicity of exhaust expelled from combustion chambers **408** and **408'**. After-treatment system **410** may include a first and second three-way catalytic converters (TWC) **412** and **412'**. Each TWC **412**, **412'** may include an oxidation catalyst **412*a*** such as a diesel oxidation catalyst (DOC), an exhaust treatment device **412*b*** such as a lean NOx trap (LNT), a particulate filter **412*c*** such as a diesel particle filter (DPF) or a gasoline particle filter and/or a reduction catalyst **412*d*** such as a selective catalytic reduction (SCR) or a urea selective reduction catalyst. Engine **402** may be located upstream of after-treatment system **410**. Within after-treatment system **410**, oxidation catalyst **412*a*** may be disposed upstream of one or more exhaust treatment devices **412*b***, particulate filters **412*c***, and reduction catalysts **412*d***. Exhaust from the first set of combustion chambers **408** may be purified by first TWC **412** and exhaust from the second set of combustion chambers **408'** may be purified by second TWC **412'**. For optimal function, first and second TWCs **412** and **412'** may be heated to optimal temperature ranges, for example, by first and second heaters **414** and **414'** (e.g., electrically heated converters (EHC)), respectively.

Heaters **414** and **414'** may heat TWCs **412** and **412'** to temperatures within a predetermined optimal or effective catalyst temperature range. The optimal temperature range may depend upon the type of engine **402** and the type of after-treatment system **410**. In one example, the optimal temperature range for operating a lean NOx trap (LNT) device is from 250° C. to 500° C. At temperatures less than 250° C., in some embodiments, NO to NO2 oxidation kinetics are too slow to effectively oxidize the NO in the exhaust gas feedstream, and the NOx reduction kinetics under rich engine operation are too slow to regenerate NOx storage sites in a timely manner during ongoing engine operation. At temperatures greater than 500° C., in some embodiments, NOx molecules may become unstable under lean engine operation, making the LNT device unable to store sufficient amount of NOx molecules. Therefore maintaining the LNT device within the optimal temperature range may increase after-treatment efficiency and decrease NOx emissions. Other target temperature ranges may include 250° C.-350° C. for catalytic converters and 600° C. to about 700° C. for diesel particulate filters.

Achieving temperatures in these optimal temperature ranges may take time. For example, if heaters **414** and **414'** are started at the time of the start of engine **402**, heaters **414** and **414'** may achieve optimal temperatures after a time delay (e.g., 150 seconds) after the start of engine **402**. Accordingly, exhaust generated during the time delay (e.g., the first 150 seconds after starting engine **402**) may be improperly purified to cause engine **402** to expel exhaust with relatively high toxicity.

According to embodiments of the invention, an after-treatment control module **416** may operate after-treatment system **410** fully or partially independently of control module **401** operating engine **402**. After-treatment control module **416** may provide energy to heaters **414** and **414'** prior to starting or running engine **402**, for example, to pre-heat after-treatment system **410** (e.g., TWCs **412** and **412'**). After-treatment system **410** may initiate pre-heated prior to or by the time engine **402** is started to reduce or eliminate the time delay associated with achieving full after-treatment efficiency. Accordingly, pre-heating after-treatment system **410** may lower toxic emissions during the full operational duration of the vehicle, extend the lifespan of after-treatment system **410** and minimize the fuel penalty. For example, if after-treatment system **410** were heated by engine **402**, engine **402** would output work for operating the vehicle as well as heating after-treatment system **410**, stressing the engine **402** and decreasing fuel efficiency.

After-treatment control module **416** may use energy from a low-voltage energy storage system (ESS) **418** (e.g., low-voltage battery **110** of FIG. **1**) to provide relatively low-voltage energy to heaters **414** and **414'** to achieve optimal temperatures over a relatively longer time delay (e.g., 20-30 minutes) or energy from a high-voltage battery (e.g., high-voltage battery **112** of FIG. **1**) to provide relatively high-voltage energy to heaters **414** and **414'** to achieve optimal temperatures over a relatively shorter time delay (e.g., 2-3 minutes).

In some embodiments, after-treatment control module **416** may use solar power energy from a solar energy source to fully or partially power heaters **414** and **414'**. After-treatment control module **416** may retrieve solar energy from photovoltaic (solar energy) sources **420**, for example, stored in low-voltage energy storage system **418**.

After-treatment control module **416** may be in communication with a vehicle telemetrics source **422** and/or a mobile device **424**, such as, a smart phone, to retrieve information to allocate power or generate a schedule or timeline for pre-heating after-treatment system **410**.

In some embodiments, a user or vehicle (with one or more associated users) may have a driving schedule (e.g., expected times when the user typically drives, such as, before and after work during the user's weekday commute, before and after meeting times for clubs or sport practices on the weekends, etc.), for example, stored in vehicle telemetrics source **422** or mobile device **424**. After-treatment control module **416** may use the driving schedule to activate heaters **414** and **414'** to pre-heat after-treatment system **410** to optimal temperatures by the times when engine **402** is expected to be started. The user may be alerted that the after-treatment system has begun pre-heating and/or that pre-heating is complete, for example, via an alert or alarm on their mobile device **424**. The user may verify (or ignore) the prompt to initiate, continue, or not cancel pre-heating after-treatment system **410** or, conversely, may reject (or ignore) the prompt to stop, cancel or not initiate pre-heating after-treatment system **410**. In another embodiment, a user may have a control button, for example, a virtual button on mobile device **424**, a physical button in the vehicle, or a partial turning of an ignition key to initiate pre-heating after-treatment system **410**.

In some embodiments, after-treatment control module **416** may use weather information (e.g., temperature, clouds, time of sunrise/sunset, etc., provided by vehicle telemetrics source **422** or mobile device **424**) to determine an amount of energy to allocate to pre-heat after-treatment system **410**. In some embodiments, if the weather information indicates future temperature fluctuations, after-treatment control module **416** may compensate for such weather changes by likewise changing the energy allocated to heaters **414** and **414'** to maintain after-treatment temperature within the optimal range. After-treatment control module **416** may alter the energy allocated to heaters **414** and **414'** prior to the expected future weather changes, for example, by an amount of time estimated to take heaters **414** and **414'** to achieve the expected temperature compensation. In some embodiments where after-treatment control module **416** uses energy from photovoltaic sources **420**, after-treatment control module **416** may provide information related to the geographical location of the vehicle and may receive a sunlight schedule indicating measures of predicted future sunlight available to the vehicle over time based on the geographical location of the vehicle. After-treatment control module **416** may change the amount of energy from photovoltaic sources **420** reserved for after-treatment system **410** based on the sunlight schedule. In one example, if the sunlight schedule predicts clouds or a decrease in the future amount of available sunlight, after-treatment control module **416** may reserve an increased or maximum amount of current solar energy resources from photovoltaic sources **420** to be stored in low-voltage energy storage system **418** to compensate for the predicted future decrease in sunlight. Conversely, if the sunlight schedule predicts direct sun or an increase in the future amount of available sunlight, after-treatment control module **416** may reserve relatively less or a minimum amount of solar energy resources for after-treatment system **410** and may distribute the remaining available energy from photovoltaic sources **420** to be used for other functionality.

In some embodiments, after-treatment control module **416** may use vehicle driving modes or status (e.g., park mode, drive mode, idle mode, start/stop mode, accelerating, decelerating, etc., which for example may be provided by vehicle telemetrics source **422**) to determine an amount of energy to allocate to pre-heat after-treatment system **410**. The driving modes may be measured by for example sensing the engine **402** operation or monitoring the gears of the vehicle. The driving modes may be sensed or predicted (e.g., a driving mode to be expected in the future may be a predicted driving mode) using real time traffic information, for example, provided by vehicle telemetrics source **422** and/or a mobile device **424**. In one example, when engine **402** is in a park, stop or idle mode, engine **402** may cool to lower temperatures and after-treatment control module **416** may allocate more energy to heaters **414** and **414'** to heat after-treatment system **410** to compensate for the temperature reduction. Similarly, when engine **402** is in a driving or start/stop mode, engine **402** may heat to higher temperatures and after-treatment control module **416** may allocate less energy to heaters **414** and **414'** to heat after-treatment system **410** to compensate for the temperature increase. In some embodiments, after-treatment control module **416** may be in ongoing communication with an after-treatment system **410** temperature sensor to receive temperature measurements over time and may modulate energy or power allocations to pre-heat after-treatment system **410** accordingly.

In some embodiments, after-treatment control module **416** may use a combination of factors, e.g., driving schedule, weather information (e.g., temperature and/or sunlight schedules), and driving modes, to determine a time schedule (e.g., pre-heating start times) and/or an energy schedule (e.g., variable amounts of energy allocated over time) to pre-heat after-treatment system **410** to maintain optimal temperatures. Each set of vehicle telematics or factors used to control pre-heating may provide an extra degree of freedom to control after-treatment system **410**.

Other numbers, types and configurations of combustion chambers, exhaust valves, air-fuel ratios, engines, fuels, and after-treatment systems may be used.

FIG. **5** is a schematic diagram of a system **500** according to an embodiment of the present invention.

System **500** may include an after-treatment system **504** in fluid (e.g., liquid or gas) communication with combustion chambers of an engine **502** to purify exhaust **520** generated by engine **502**. After-treatment system **504** may purify by for example converting toxic emission in exhaust **520** such as nitrogen oxides (NOx) to less toxic or non-toxic emissions **522**, such as nitrogen (N_2). System **500** may include a temperature sensor (T) to measure temperature of exhaust gas and an air-fuel ratio sensor (A/F) to measure the oxygen concentration of the exhaust gas.

After-treatment system **504** components may include one or more two or TWCs **506**, one or more exhaust treatment devices **508**, one or more reduction catalysts **510**, one or more particulate filters **512**. One or more diverter valves **518** may be provided to bypass or alter the exhaust flow through one or more after-treatment components **506**, **508**, **510** and **512**, for example, to execute an after-treatment process using any combination and any order of these components.

After-treatment components **506**, **508**, **510** and **512** may each function at optimal efficiency within a same or different predetermined temperature range(s). An after-treatment control module **516** may provide electric energy to heaters **514***a*, **514***b*, **514***c* and **514***d* (e.g., electrically heated converters (EHC)) to heat after-treatment components **506**, **508**, **510** and **512** to temperatures within the predetermined temperature ranges associated with optimal efficiency for the respective components. Since one or more after-treatment components **506**, **508**, **510** and **512** may have different associated predetermined temperature ranges, one or more heaters **514***a*, **514***b*, **514***c* and **514***d*, may be heated independently and within different (partially or non-overlapping) temperature ranges.

After-treatment control module **516** may provide solar generated electric energy to heaters **514***a*, **514***b*, **514***c* and **514***d*, for example, generated at photovoltaic cells (e.g., photovoltaic sources **106** of FIG. **1**). The solar generated electric energy provided to the after-treatment system to purify exhaust from engine **502** may be separately stored and independently controlled from the energy used to start or ignite engine **502**. Solar generated energy provided to the after-treatment system may be stored in a relatively low-voltage energy storage system (e.g., low-voltage battery **110** of FIG. **1**), while energy used to start engine **502** may be stored in a relatively high-voltage energy storage system (e.g., high-voltage battery **112** of FIG. **1**).

Solar generated electric energy may power heater **514***a* to provide primary or auxiliary heat to TWC **506** for carbon monoxide (CO), UHC oxidation, ammonia (NH_3) generation and/or oxygen storage capacity (OSC) management, which may be monitored since TWC **506** and LNT typically have very small oxygen storage capacity. Solar generated electric energy may power heater **514***b* to provide primary or auxiliary heat to exhaust treatment devices **508** to maintain the temperature of a lean NOx trap (LNT), achieve faster light-off temperature (e.g., the minimum temperature threshold for after-treatment system **504** to functioning optimally, which may depend on the driving mode), to manage temperatures for the regeneration and/or sulfation of nitrogen oxides (NOx), to manage the timing of the sulfation of nitrogen oxides (NOx), and/or to manage the timing for switching between lean and rich stoichiometric operations. Solar generated electric energy may power heater **514***c* to provide primary or auxiliary heat to reduction catalysts **510** to manage injecting urea for ammonia (NH_3) formation, injecting air to make oxygen (O_2) available for selective catalytic reduction reactions and/or to maintain optimal temperatures at heater **514***c* during idle or decelerating driving modes. Solar generated electric energy may power heater **514***d* to provide primary or auxiliary heat to particulate filters **512** to filter particulate matter from the exhaust, manage the timing of active and/or passive regeneration, and/or monitor pressure drops.

It may be appreciated that if two or more of after-treatment components **506**, **508**, **510** and **512** have the same or overlapping optimal temperature ranges, the components may be heated by a single heater **514***a*. In other embodiments, a single heater may provide multiple temperatures, for example, at different locations, nodes or distances from the heater or at different times to heat multiple different after-treatment components **506**, **508**, **510** and **512** to temperatures within different optimal temperature ranges. It may also be appreciate that other after-treatment systems, components or arrangements of components may be used.

FIG. **6** is a schematic diagram of a system **600** according to an embodiment of the present invention.

System **600** may include an after-treatment system **604** for purifying exhaust generated by an engine **602**. A throttle **606** may supply or control the supply of energy or fuel, to engine **602**. Engine **602** may ignite the fuel in one or more combustion chambers to start engine **602** and may release toxic exhaust as a byproduct into after-treatment system **604**. System **600** may include a fuel injector **608**, which may be internal (in-cylinder) or external to engine **602**, to inject fuel directly into the exhaust stream.

After-treatment system **604** may include an oxidation catalyst **610** such as a diesel oxidation catalyst (DOC), which may generate an exothermal reaction to oxidize the exhaust stream and injected fuel, and/or a particulate filter **612** such as a diesel particle filter (DPF) to filter particulate matter from the exhaust stream. One or more heaters **614***a*, **614***b* (e.g., heaters **414** and **414'** of FIG. **4**) may heat oxidation catalyst **610** and particulate filter **612**, respectively, to temperatures within respective predetermined optimal functional ranges. Oxidation catalyst **610** may output an oxidized exhaust stream that, for example, depending on the actuation of a valve **620** (e.g., EGR valve **406** of FIG. **4**), may be directed to particulate filter **612** or diverted to be re-cycled through engine **602**.

System **600** may include a photovoltaic (solar energy) source **616** (e.g., photovoltaic sources **106** of FIG. **1**) to store energy in an energy storage system (ESS) **618** (e.g., low-voltage battery **110** of FIG. **1**) or to distribute the energy directly to system **600** components. Power actuators (e.g., controlled by after-treatment control module **416** of FIG. **4**) may distribute the energy from photovoltaic source **616**, for example, to heaters **614***a*, **614***b*, throttle **606** and/or valve **620**.

Power actuators may control throttle **606** to regulate when and/or how much fuel is provided to engine **602**. Power actuators may control valve **620** to re-circulate engine exhaust back to engine **602**. In some embodiments, power actuators may use vehicle telematics to control the allocation of energy from photovoltaic source **616** to system components, for example, according to the driving mode.

Other after-treatment systems, components or arrangements of components may be used.

FIG. **7** is a schematic diagram of a system **700** according to an embodiment of the present invention.

System **700** may include an after-treatment system **704**. After-treatment system **700** may include power actuators (e.g., controlled by after-treatment control module **416** of FIG. **4**) to distribute solar electric energy, for example, directly from photovoltaic sources **702** (e.g., photovoltaic sources **106** of FIG. **1**) or from an intermediate energy storage system **716** (e.g., low-voltage battery **110** of FIG. **1**). Power actuators may include electro-mechanical switches, valves or other devices, for example, having open/closed activation settings or a continuous scale of activation settings, to activate one or more after-treatment system **700** components.

After-treatment system **700** components may include a catalytic converter **706** (e.g., TWC **412** and/or LNT **412***b* of FIG. **4**), a selective reduction catalyst **708** (e.g., SCR **412***d*), and/or a urea or ammonia (NH_3) selective reduction catalyst **710**. After-treatment component **706**, **708**, **710** may be conductively connected to heaters **712***a*, **712***b*, **712***c* (e.g., heaters **414**, **414'** of FIG. **4**), respectively, to heat the components to optimal efficiency temperatures. Injectors **714***a* and **714***b* may inject air and injector **714***c* may inject urea into the exhaust stream input into after-treatment component **706**, **708**, **710**, respectively.

Power actuators may control the amount of energy generated at photovoltaic sources **702** that is allocated to heaters **712***a*, **712***b*, **712***c* to control the temperatures and timing the temperatures thereof and/or the amount of energy allocated to injectors **714***a*, **714***b*, **714***c* to control the amount of air or urea injected and the timing of the injections. Power actuators may provide energy from photovoltaic sources **702** to heaters **712***a*, **712***b*, **712***c* to generate auxiliary heat to maintain minimum temperatures at catalytic converter **706**, for example, for carbon monoxide (CO) and/or hydrocarbon (HC) oxidation, ammonia (NH_3) generation and/or regeneration and desulfation of nitrogen oxides (NOx). In some embodiments, power actuators may use vehicle telematics to control the allocation of energy from photovoltaic sources **702** to system components to manage, for example, the timing and/or duration of LNT regeneration, the timing and/or duration of in situ ammonia generation, the timing and/or duration of air injections by air injectors **714***a*, **714***b*, and/or the timing and/or duration of urea injections by urea injector **714***c* for urea decomposition, hydrolysis and NH3 formation by urea selective reduction catalyst **710**.

Other after-treatment systems, components or arrangements of components may be used.

FIG. **8** is a schematic diagram of an after-treatment system **800** operating in low temperature conditions **802** and high temperature conditions **803** according to an embodiment of the present invention. Although the same components **804**-**812** are included in system **800** in both low and high temperature conditions **802**, **803**, different components may be used (and not used) in each set of conditions **802**, **803**, for example, by way of a diverter valve **812**.

After-treatment system **800** may be in fluid communication with and downstream from an engine **802** to process and decrease the toxicity of the engine exhaust. After-treatment system **800** may include power actuators to distribute energy from a solar energy source (e.g., photovoltaic sources **106** of FIG. **1**) to after-treatment system **800** components.

After-treatment system **800** may include a sequence of two or more components, for example, including one or more three-way catalysts **806***a* and/or **806***b* (e.g., TWC **412** of FIG. **4**) and a series of two or more **808** and/or **810** lean NOx traps (LNTs) (e.g., exhaust treatment device **412***b* of FIG. **4**) and/or selective reduction catalysts (e.g., SCR **412***d*). One or more diverter valves **812** may be used to bypass or alter the exhaust flow (e.g., indicated in FIG. **8** by doted lines) through one or more after-treatment components **806***a*, **806***b*, **808**, and/or **810**. In the example shown in FIG. **8**, during low temperature conditions **802**, diverter valve **812** may be actuated in a first position to allow exhaust to flow sequentially through components **806***a*/**806***b*, **808**, **810**, while during high temperature conditions **803**, diverter valve **812** may be actuated in a second position to divert exhaust to bypass the first LNT/SCR components **808** and flow sequentially through components **806***a*/**806***b* and **810**. Alternatively, other components may be used in other conditions and/or other orders. The actuation position of diverter valve **812** and the corresponding activated after-treatment components may correspond to different modes, for example, shown in FIG. **3** including different driving conditions. Diverter valve **812** may be activated by the power actuators using energy from a solar energy source. Diverter valve **812** may include additional actuation positions other than the two shown in FIG. **8**. In some embodiments, power actuators may use vehicle telematics to determine when to switch diverter valves **812**, for example, depending on driving modes, weather conditions, traffic reports, geographical information such as altitude or pressure changes, curving roads, or other environmental factors.

FIG. **9** is a graph of temperatures of an after-treatment system with respect to time according to an embodiment of the present invention. Target temperature **901** may be an optimal temperature (or median of an optimal temperature range) for optimal after-treatment system performance. In the example of graph **900** in FIG. **9**, target temperature **901** is 300° C., although other target temperatures may be used for different after-treatment processes and devices. Time **902** may be the start time of an engine purified by the after-treatment system.

Graph segment **904** starting at engine start time **902** and ending at subsequent time **906** may represent the temperatures of the after-treatment system where heating is initiated by the start of the engine at start time **902**. Once the engine is started, temperatures increase at a relatively fast rate, for example, by way of heat generated by operating the engine and/or using a main high-voltage vehicle battery. However, there is a predetermined time delay after the start of the engine at start time **902** until subsequent time **906**, during which the after-treatment system is operating at sub-optimal temperatures and therefore at sub-optimal efficiency. The duration of this time delay during which the after-treatment system has sub-optimal performance may be, for example, 150 seconds, and may vary depending on the type of engine, fuel, after-treatment system, and target temperature **901**.

According to embodiments of the invention, after-treatment system may include heaters (e.g., heater **414** of FIG. **4**) to initiate pre-heating at an after-treatment start time **908** independent of and prior to engine start time **902**. After-treatment start time **908** may begin prior to engine start time **902** by a time difference, for example, less than, equal to, or greater than the time delay used to achieve the system's optimal functional temperature. Accordingly, the time delay during which the after-treatment system has sub-optimal temperatures (and therefore sub-optimal performance) may be shifted from after engine start time **902** to before engine start time **902**. Shifting the start time **908** for pre-heating after-treatment system to before the engine start time **902** may reduce or eliminate extraneous toxic emissions generated at sub-optimal temperatures. In some embodiments, pre-heating may be powered by solar energy sources, which may have a relatively longer time delay to pre-heat the after-treatment system (e.g., twenty minutes) than conventional vehicle energy sources (e.g., two to four minutes) and may be started earlier to account for the extra length of the relatively longer time delay. After-treatment system may be heated to target temperature **901** before or at start time **902** or at least before subsequent time **906**.

Once target temperature **901** is achieved, temperatures of the after-treatment system may fluctuate above and below target temperature **901**, for example, depending on the work done by the engine due to driving conditions, such as, acceleration, deceleration, idling, etc. After-treatment heaters may be operatively linked to temperature sensors monitoring temperatures of the after-treatment components. As the temperatures of the after-treatment system components fluctuate, the energy provided to heaters may be adjusted to complement the sensed temperatures to maintain component temperatures approximating target temperature **901**, for example, for as long as the engine is operational for optimal after-treatment performance.

FIG. **10** is a flowchart of a method according to an embodiment of the present invention.

In operation **1000**, energy may be received from a solar energy source (e.g., photovoltaic sources **106** of FIG. **1**) electrically connected to an after-treatment system (e.g., after-treatment system **114** of FIG. **1**). The solar energy source may be electrically connected to the after-treatment system directly or via intermediate components such as a controller, batteries, etc.

In operation **1010**, a control module (e.g., after-treatment control module **416** of FIG. **4**) may provide at least some (e.g., a portion, a fraction, or all) of the energy from the solar energy source to the after-treatment system. For example, some (e.g., some fraction) or all electricity from photovoltaic sources may be provided to the after-treatment system.

In operation **1020**, the control module may provide at least some of the energy from the solar energy source to a heater (e.g., heater **414** of FIG. **4**), for example, to initiate heating the after-treatment system prior to starting the engine. In some embodiments operations **1000-1020** may occur before the engine of the vehicle is turned on.

In operation **1030**, the control module may provide an alert or alarm when the after-treatment system is heated to temperatures within a predetermined temperature range associated with optimal efficiency for the after-treatment system. The alarm may indicate that the engine is started with optimal or above threshold after-treatment results.

Other operations or series of operations may be used.

Embodiments of the present invention may include apparatuses for performing the operations described herein. Such apparatuses may be specially constructed for the desired purposes, or may comprise computers or processors selectively activated or reconfigured by a computer program stored in the computers. Such computer programs may be stored in a computer-readable or processor-readable storage medium, any type of disk including floppy disks, optical disks, CD-ROMs, magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs) electrically programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs), magnetic or optical cards, or any other type of media suitable for storing electronic instructions. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein. Embodiments of the invention may include an article such as a non-transitory computer or processor readable storage medium, such as for example a memory, a disk drive, or a USB flash memory encoding, including or storing instructions, e.g., computer-executable instructions, which when executed by a processor or controller, cause the processor or controller to carry out methods disclosed herein. The instructions may cause the processor or controller to execute processes that carry out methods disclosed herein.

Features of various embodiments discussed herein may be used with other embodiments discussed herein. The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. It should be appreciated by persons skilled in the art that many modifications, variations, substitutions, changes, and equivalents are possible in light of the above teaching. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

What is claimed is:

1. A control system for solar-powered exhaust after-treatment system comprising:
- a plurality of photovoltaic cells mounted on a vehicle;
- an energy storage system having separate high voltage and low voltage storage batteries;
- a power control module, stored in a memory, configured to allocate electricity generated by the photovoltaic cells between the high voltage and the low voltage storage batteries in accordance with predicted sunlight availability received from one or more telemetric providers; and
- an after-treatment system powered from electricity from the energy storage system, the after-treatment system in communication with an after-treatment control module, stored in a memory, configured to distribute electricity from the energy storage system to the after-treatment system in accordance with a driving mode in which the vehicle is operating.

2. The system of claim **1**, wherein the after-treatment control module is further configured to direct electricity from the energy storage system in accordance with predicted driving modes received from the one or more telemetric providers.

3. The system of claim **1**, wherein the driving mode includes a park mode.

4. The system of claim **3**, wherein the driving mode includes a state of acceleration.

5. The system of claim **1**, wherein the driving mode includes a state of deceleration.

6. The system of claim **5**, wherein the after-treatment system includes a heater, which further includes an electrically heated converter (EHC).

7. The system of claim **1**, wherein the after-treatment control module is further configured to allocate power to the exhaust after-treatment system responsively to detection of a threshold temperature by at least one temperature sensor disposed in the exhaust after-treatment system.

8. The system of claim **5**, wherein the energy storage system is configured to receive electricity from the photovoltaic cells at a voltage exceeding a storage voltage of the low voltage storage battery of 12 volts.

9. The system of claim **8**, wherein the energy storage system is configured to receive electricity from the photovoltaic cells at a voltage ranging between 13.5 and 16.5volts.

10. The system of claim **1**, further comprising a DC-DC converter configured to increase voltage of electricity received from the photovoltaic cells.

11. A method for allocating energy to a solar-powered exhaust after-treatment system comprising:

using a power control module, stored in a memory, to:

allocate electricity generated by photovoltaic cells between high voltage and low voltage storage batteries in accordance with predicted sunlight availability received from one or more telemetric providers, wherein the high voltage and low voltage storage batteries comprise at least part of an energy storage system; and

distribute electricity from the energy storage system to an after-treatment system in a vehicle in accordance with a driving mode in which the vehicle is operating.

12. The method of claim **11**, wherein the driving mode includes a parking mode.

13. The method of claim **11**, wherein the driving mode includes a state of deceleration or acceleration.

14. The method of claim **11**, wherein the power control module is further configured to distribute electricity from the

energy storage system in accordance with predicted driving modes received from the one or more telemetric providers.

15. The method of claim **11**, wherein the power control module is further configured to allocate electricity generated by photovoltaic cells between the high voltage and the low voltage storage batteries in accordance with geographical factors received from the one or more telemetric providers.

16. The method of claim **15**, wherein the geographical factors includes terrain.

17. The method of claim **15**, wherein the wherein the geographical factors includes altitude.

18. The method of claim **16**, wherein the energy storage system is configured to receive electricity from the photovoltaic cells at a voltage exceeding a storage voltage of the low voltage storage battery of 12 volts.

19. The method of claim **18**, wherein the energy storage system is configured to receive electricity from the photovoltaic cells at a voltage ranging between 13.5 and 16.5 volts.

20. The method of claim **11**, wherein the energy storage system is linked to a DC-DC converter, the DC-DC convertor configured to increase voltage of electricity received from the photovoltaic cells.

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